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Solar air conditioning in Europe—an overview

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Abstract

Summer air conditioning represents a growing market in buildings worldwide, with a particularly significant growth rate observed in European commercial and residential buildings. Heat-driven cooling technologies are available, which can be used in combination with solar thermal collectors to alleviate the burden caused by air conditioning on the electric utilities and the environment. Solar air conditioning has progressed considerably over the past years as a result of efforts toward environmental protection and new developments in components and systems, and significant experience has been gained from demonstration projects. The main obstacles for large scale application, beside the high first cost, are the lack of practical experience and acquaintance among architects, builders and planners with the design, control and operation of these systems.

This paper describes the main results of the EU project SACE (Solar Air Conditioning in Europe), aimed to assess the state-of-the-art, future needs and overall prospects of solar cooling in Europe. A group of researchers from five countries has surveyed and analyzed over 50 solar-powered cooling projects in different climatic zones. The paper presents a short overview on the state-of-the-art and potential of solar-assisted cooling and air conditioning technologies. The results of the study, including a database of the surveyed projects, an evaluation of these projects on a uniform basis, an economic analysis tool, user guidelines and a multimedia tool—are presented. The potential energy

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savings and limitations of solar thermal air conditioning in comparison to conventional technologies are illustrated and discussed.

Keywords: Solar air conditioning; Solar cooling; Solar thermal energy; Absorption; Adsorption

Contents

1. Introduction

Energy consumption in commercial and residential buildings represents approximately 40% of Europe's energy budget. The final energy consumption for 2002 in the building sector amounted to 435 Mtoe or 40.3% of the total EU-25 final energy use [1]. The higher living and working standards, the adverse outdoor conditions in urban environments and reduced prices of air-conditioning units, have caused a significant increase in demand for air conditioning in buildings, even where there was hardly any before. The number of installed air-conditioning systems in Europe with cooling capacity over 12 kW has increased by a factor of 5 in the last 20 years [2]. Total air-conditioned floor space has grown from 30 million m^2 in 1980 to over 150 million m^2 in 2000. Annual energy use of room air conditioners was 6 TJ in 1990, 40 TJ in 1996 and is estimated to reach 160 TJ in 2010.

The fast growing demand for air conditioning has imposed a significant increase in demand for primary energy. Electric utilities have their peak loads in hot summer days, and are often faced with brown-out situations, barely capable of meeting the demand. The resulting CO_2 emissions in the EU are expected to increase by a factor of 20 from 1990 to 2010.

With suitable technology, solar cooling can help alleviate the problem. The fact that peak cooling demand in summer is associated with high solar radiation offers an excellent opportunity to exploit solar thermal technologies that can match heat-driven cooling technologies. Of particular interest are urban areas where adverse outdoor conditions, as a

result of higher outdoor pollution and the urban heat island effect, encourage the use of mechanical air-conditioning with a direct impact on peak electrical energy use [3].

Commercial application of solar energy for air conditioning purposes is relatively new. Lamp and Ziegler [4] give an overview of the European research on solar-assisted air conditioning up to 1996. Tsoutsos et al. [5] present a study of the economic feasibility of solar cooling technologies. Karagiorgas et al. [6] investigated the application of renewable technologies in the European tourism industry and identified a large number of solar thermal systems but only a few solar cooling systems. Different heat-driven cooling technologies are available on the market, particularly for systems of above 40 kW, which can be used in combination with solar thermal collectors. The main obstacles for largescale application, beside the high first cost, are the lack of practical experience and acquaintance among architects, builders and planners with the design, control and operation of these systems. For smaller scale systems, there is no market available technology. Therefore, the development of low power cooling and air conditioning systems is of particular interest. Heat-driven cooling technologies include mainly closed cycles (absorption, adsorption) and open cycles (desiccant systems) [7,8]. A more detailed discussion of these systems is given in Section 2.

Solar assisted cooling systems usually involve solar thermal collectors connected to thermally driven cooling devices. They consist of several main components (Fig. 1): the solar collectors; a heat buffer storage; the heat distribution system; the heat-driven cooling device; an optional cold storage; the air conditioning system, including various forms of cold distribution; and auxiliary (backup) subsystem. The auxiliary subsystem may, in principle, be integrated at different places in the overall system: as an auxiliary heater parallel to the collector or the collector/storage, or as an auxiliary cooling device, or both.

The SACE (Solar Air Conditioning in Europe) project was initiated in early 2002 and conducted over the next 2 years by a group of researchers from five countries, supported by

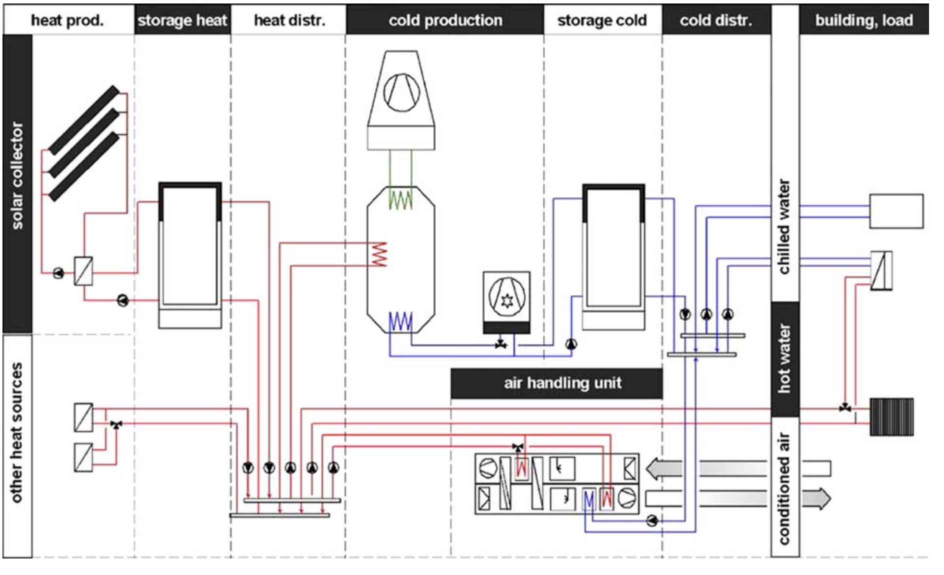


Fig. 1. Schematic description of solar air-conditioning system, showing various component options.

the European Commission. The project's main objectives were to examine the state-of-the-art of environmentally friendly air conditioning, to asses the potential of various heatdriven cooling technologies for use with solar thermal systems, to identify future needs and evaluate the overall prospects of solar cooling in Europe. The first step was to collect information about existing systems: over 50 solar-powered cooling projects in different climatic zones were surveyed and analyzed. A standardized method was developed and used to compare these systems to each other on a uniform basis, and establish a set of performance criteria for them. Guidelines for implementation and an economic analysis tool were also part of this work. Finally, a multimedia tool was developed to help disseminate the information and to keep it up-to-date by interacting with users through an Internet web site.

The paper presents a short overview on the state-of-the-art and potential of solarassisted cooling and air conditioning technologies. The results of the SACE study, including a database of the surveyed projects, an evaluation of these projects, an economic analysis tool, user guidelines and a multimedia tool—are presented. The potential energy savings and limitations of solar thermal air conditioning in comparison to conventional technologies are illustrated and discussed.

2. Technologies for solar-driven cooling and air conditioning

A discussion of solar cooling technologies is given in [3–5,7,9,10]. The article by Grossman [7] presents an overview of solar cooling, including thermodynamic considerations. The handbook by Henning [10] also includes practical design aspects. The systems under consideration are generally divided into two main categories—closed and open cycles.

2.1. Closed-cycle systems

These types of systems are based mainly on the absorption cycle, which constitutes, thermodynamically, of a heat engine driving a heat pump. In its simplest, single-effect configuration, an absorption system employs a refrigerant expanding from a condenser to an evaporator through a throttle, in much the same way as in the conventional vapor compression system. A second working fluid—the absorbent—is employed, which absorbs refrigerant vapor from the evaporator at low pressure, and desorbs into the condenser at high pressure, when heat is supplied to the desorber. The absorption system is hence a heat-driven heat pump; the heat may come from a variety of sources, including solar, waste heat and the like. The system operates between two pressure levels, and interacts with heat sources/sinks at three temperature levels: The low temperature cooling in the evaporator; the intermediate temperature heat rejection in the absorber and condenser; and the high temperature (solar) heat supply in the desorber. A variety of working fluids have been proposed; the two most common absorbent–refrigerant pairs are LiBr–water and water–ammonia.

A key figure to describe the performance of a thermally driven chiller is the thermal Coefficient of Performance (COP), defined as the produced cold per unit of driving heat. Single-effect absorption systems are limited in COP to about 0.7 for LiBr–water and to 0.6 for ammonia–water, and hence require a rather large solar collector area to supply the heat needed for their operation. This collector area can be reduced by employing systems with

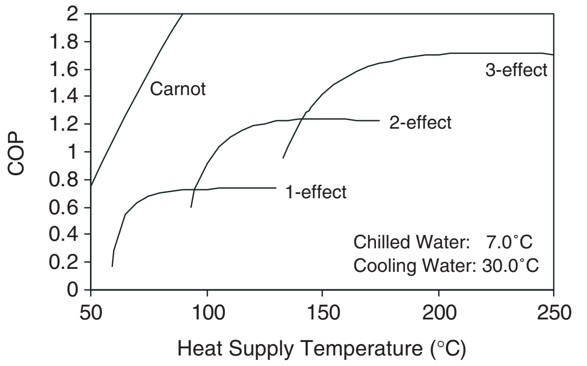


Fig. 2. Coefficient of Performance (COP) as a function of (solar) heat supply temperature for single-, double- and triple-effect LiBr–water absorption chillers [7].

improved COP, which may be achieved using a higher temperature heat source. In this case, the absorption systems must be configured in stages [11]. The principle is to utilize the heat rejected from the condenser to power additional desorbers, thereby approximately doubling or tripling the amount of refrigerant extracted out of solution with no need for additional solar heat. These systems need, however, high temperature collectors, such as evacuated tube or concentrating collectors. The higher cost of the cooling machine and the solar collector should hence be considered.

Most solar-powered absorption cooling projects to-date have utilized single-effect systems, with low-temperature solar collectors. Developments in gas-fired absorption systems in recent years, mainly in the USA and Japan, for LiBr–water chillers, have made available in the market double-effect systems with COP in the range 1.0–1.2. Triple-effect systems are still under development but close to the market, with COP of about 1.7. These systems may be adapted to and employed in a solar-powered installation with hightemperature solar collectors. Fig. 2 compares the performance of several multi-effect chillers, showing the COP as a function of the solar heat supply temperature for typical single-, double-and triple-effect chillers with the same component size and under the same operating conditions. The corresponding Carnot performance curve is also shown for comparison. The single-effect system gives best results in the temperature range 80–100 °C; for a higher supply temperature, it is worth switching to a double effect system, up to about 160 °C, and then to a triple-effect. Absorption chillers are available from various manufacturers, in large capacities up to several thousands kilowatts. However, in the range of small capacities (<100 kW) only very few systems are available in the market.

Adsorption chillers working with solid sorption materials are also available. The main difference compared to the absorption systems is that two or more adsorbers are necessary in order to provide continuous operation. Adsorption systems allow for somewhat lower driving temperatures but have a somewhat lower COP compared to absorption systems under the same conditions. Silica gel adsorption machines with cooling capacities of about 75 kW to several hundreds kiloWatt are produced in Japan. Small adsorption machines are not commercially available yet, but are expected to enter the market in the near future. The simplicity of the process, the wide range of heating temperatures and other advantages

such as noiseless operation could lead to a large number of small solar assisted air conditioning applications. Further research and development work on small-size adsorption machines is necessary in order to reduce their volume and increase the power density.

2.2. Open-cycle systems

Desiccant systems are essentially open sorption cycles, utilizing water as the refrigerant in direct contact with air. The desiccant (sorbent) can be either solid or liquid and is used to facilitate the exchange of sensible and latent heat of the conditioned air stream. The term ‘open’ is used to indicate that the refrigerant is discarded from the system after providing the cooling effect and new refrigerant is supplied in its place in an open-ended loop. In this type of systems the process air is treated in a dehumidifier and goes through several additional stages before being supplied to the conditioned space. The sorbent is regenerated with ambient or exhaust air heated to the required temperature by the solar heat source. Most desiccant systems presently on the market use a solid sorption material such as silica gel. Since the solid desiccant cannot be circulated by pumping, these systems usually employ a rotary bed carrying the sorbent material, referred to as a ‘desiccant wheel’, to allow continuous operation. Systems employing liquid sorption materials are less widespread but also available on the market. They have several advantages such as the ability to contain, pump and filter the desiccant, cool during absorption and heat during desorption, the possibility of energy storage by means of concentrated hygroscopic solutions, as well as bacteriostatic qualities.

3. Overview of the SACE project

The SACE (Solar Air Conditioning in Europe) project was aimed to assess the state-of-the-art and to provide a clear picture of the potential, the future needs and the overall perspectives of this technology. The main objectives of the project were: (1) To conduct a horizontal study on the state-of-the-art of environmentally friendly technologies for air conditioning of buildings in Europe with an emphasis on cooling and dehumidification (summer air conditioning) and low temperature heat-driven technologies; (2) To assess the potential of these technologies for using solar heat as the driving mechanism; (3) To achieve a broad overview about the state-of-the-art of solar assisted air conditioning in Europe; (4) To identify the strong and weak points of the reviewed technologies in relation to their energy performance, environmental impact and financial viability; (5) To identify future needs and necessary actions in order to better exploit the potential of the identified technologies and to contribute to the advancement of promising technologies, that will accelerate their introduction into the market.

In order to assess existing installations and research on components for solar assisted cooling systems, the CORDIS database of the European Commission was screened for EC funded projects; projects from the IEA Solar Heating and Cooling Program were also included in the survey. More detailed data on solar cooling applications were also collected by the SACE partners on national level, in the participating countries.

The above search has revealed many research and development projects on new components and systems, as well as demonstrations of solar-assisted air conditioning, carried out in Europe under both national and European programs. Several innovative

concepts and component developments have evolved. A standardized methodology was hence devised under the SACE project and used to collect and assess the data from the various projects, in order to provide a comparative description and evaluation of technical developments at component and system level, and to assess the performance of demonstration projects. Using these data along with a method prepared for preliminary economic investigation, a techno-economic study was performed for different heat-driven technologies (absorption, desiccant, adsorption, jet cycles) combined with different types of solar thermal collectors, for different loads and climatic conditions.

4. SACE project results

The following sections outline the main results/deliverables of the SACE project. All information is readily accessible and can be viewed on and/or downloaded from the SACE web site at *http://www.ocp.tudelft.nl/ev/res/sace.htm*

4.1. Project database

A total of 54 research, development and demonstration projects were identified and documented. For consistency, a questionnaire was developed to collect configuration, functional and economic data on each system as a basis for the subsequent project evaluation. Design data were included in all cases, and actual performance data were also included, where available. Emphasis was put on EU projects, but other dominant international projects were also included.

The questionnaire was designed to collect data which would facilitate the subsequent evaluation of all projects from the SACE database according to a set of defined evaluation criteria, classified into design parameters and actual performance parameters. The design parameters are determined from the technical system description and from the component description, and include parameters such as COP, heat sources/sinks temperature levels, component sizes and rated consumption values. A process quality number is applied, relating the COP at rated conditions to the COP of an ideal cycle at identical temperature levels. The first cost of the entire cooling system is also considered as a design parameter. On the other hand, monitored data of heat consumption, cold production, electricity and water consumption are used to calculate the actual performance evaluation parameters. The costs are expressed per produced kilowatt hour of cold.

In addition to completing the structured parts of the questionnaire, respondents were encouraged to submit photographs and informal descriptions of the various projects. These form an integral part of the project database.

The SACE database includes completed questionnaires for a total of 54 projects. About 40% of the surveyed projects are at the research stage, 40% at the development stage and 20% at the production stage. Approximately 70% of the systems employ an absorption chiller for chilled water supply; 10% use adsorption chillers, 10% use desiccant cooling systems. The remaining projects use different technologies such as steam jet chilling, or the technology applied was not specified. Research projects concentrate on absorption, adsorption, liquid desiccants, solid desiccants, chemical heat pumps, absorption–diffusion and steam jet systems. Production stage projects are dominated by absorption, using $LiBr/H_2O$ (75%) and NH_3/H_2O (25%).

4.2. Project evaluation

The evaluation criteria used to assess the projects included parameters based on: design data, such as thermal COP, driving (T_{hot}) and heat rejection ($T_{heat_rejection}$) temperature, chilled water (T_{cold}) temperature, process quality number (PQN), specific collector area ($A_{col,spec}$), storage size, solar COP, electric performance (Eff_{el}), specific water consumption ($m_{w,s}$) and cost (C); and actual performance data, such as annual thermal COP, annual electric performance, annual specific water consumption and annual actual cost.

The performance of each project included in the SACE database is illustrated using an evaluation diagram, like the one illustrated in Fig. 3. The vertical axis shows all the design and actual annual performance evaluation criteria. The horizontal bars quantify the relative score of each criterion for the project under consideration, in comparison with the average value for all the projects included in the SACE database. The relative score for each criterion is the ratio: actual value divided by the corresponding average value. The vertical line indicates the average value of each performance criterion for all the projects.

Based on the projects evaluated under SACE, single-effect absorption systems have a thermal COP in the range of 0.50–0.73, of which $LiBr/H_2O$ systems average 0.66 and NH_3/H_2O systems average 0.60. The thermal COP of double-effect absorption systems can reach 1.3 when the driving temperature is sufficiently high. In the evaluated projects, driving temperatures are in the range 60–165 °C. The majority of these systems operate below 97 °C, using flat plate solar collectors.

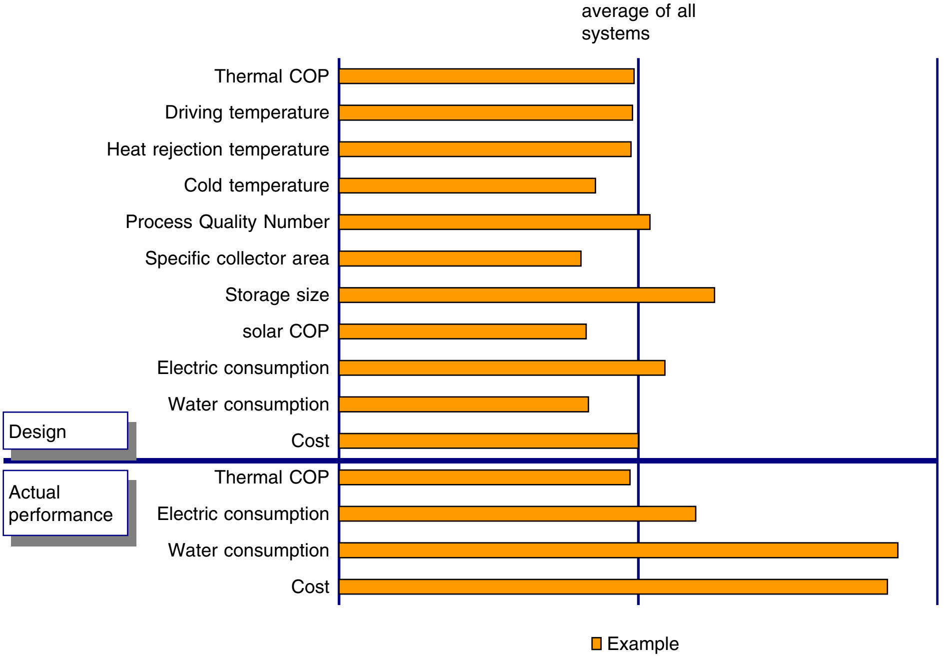


Fig. 3. Representative evaluation diagram for the assessment of project performance. A value on the left of the average line means 'low', while on the right side it means 'high', compared to the average.

Adsorption systems have a lower thermal COP, averaging 0.59. However, since adsorption systems operate at a driving temperature lower than absorption systems (52.5–82 °C), and taking into account all the working conditions including thermal COP, T_{hot}, T_{cold} and $T_{heat_rejection}$, they show a relatively high average value of PQN (0.38)—higher than the average value of all evaluated projects (0.31). If the adsorption system is driven by the lowest temperature (52.5 °C), it can reach the highest value of PQN (0.54). The process quality number, PQN, is the ratio of the thermal COP and the COP for a Carnot cycle operating under the same external conditions:

$$PQN = \frac{COP}{COP_{Carnot}} = \frac{COP}{\frac{1-\frac{T_{heat_rejection}}{T_{hot}}}{\frac{T_{heat_rejection}}{T_{cold}}-1}} \tag{1}$$

A liquid desiccant system evaluated under SACE had a thermal COP of 0.74, with a driving temperature of 66.5 °C. A project with solid desiccants had a thermal COP of 0.51. An absorption–diffusion system showed a comparatively low performance, with the lowest COP of all evaluated projects and a required high operation temperature of approximately 120 °C. In the current stage of development, this technology is less favorable for solar air-conditioning systems than commercially available absorption or adsorption systems. One steam jet pump project showed a relatively high thermal COP of 0.85 (pilot project), with a driving temperature of 117.5 °C. Since the heat supply temperature in this process is about 200 °C, the application is restricted to concentrating solar collectors.

Overall, flat plate solar collectors are widely used in 63% of the evaluated projects. Other types include the evacuated tube (21%), the compound parabolic concentrator (CPC) without tracking (10%) and the compound parabolic concentrator with tracking, which was used in some cases. The average specific solar collector area for all the reviewed projects was 3.6 m^2/kW, but with a high variety ranging from 0.5 to 5.5 m^2/kW. Adsorption and absorption systems require a specific solar flat plate collector area higher than 2 m^2/kW and usually lower than 5 m^2/kW. Overall, NH_3/H_2O systems require larger specific collector areas than H_2O/LiBr systems and as a result the installations are usually more expensive.

The driving temperature is determined by the heat-driven cooling device, and influences the system performance, with a different range of driving temperature supplied by different types of solar collectors. The driving temperature is defined as the average temperature of the heating fluid between inlet and outlet of the heating section

$$T_{hot} = \frac{T_{heating_medium_in} - T_{heating_medium_out}}{\ln \frac{T_{heating_medium_in}}{T_{heating_medium_out}}} \tag{2}$$

with the temperatures expressed in Kelvin. Based on the available data, if the driving temperature is in the range 60–90 °C, a common flat plate solar collector can be used. Using a selective surface flat plate solar collector, the driving temperature can be up to 120 °C, and with transparent insulation it can reach up to150 °C. For the projects with stationary evacuated tube solar collectors, the driving temperature is in the range 73–97 °C and 97–165 °C with compound parabolic concentrators (CPC).

The variation of the system's thermal performance (COP) with the driving temperature, T_{hot}, is illustrated in Fig. 4. The thermal COP is the ratio between the cooling capacity of the system and the heating power delivered to the system by the solar collectors, directly or

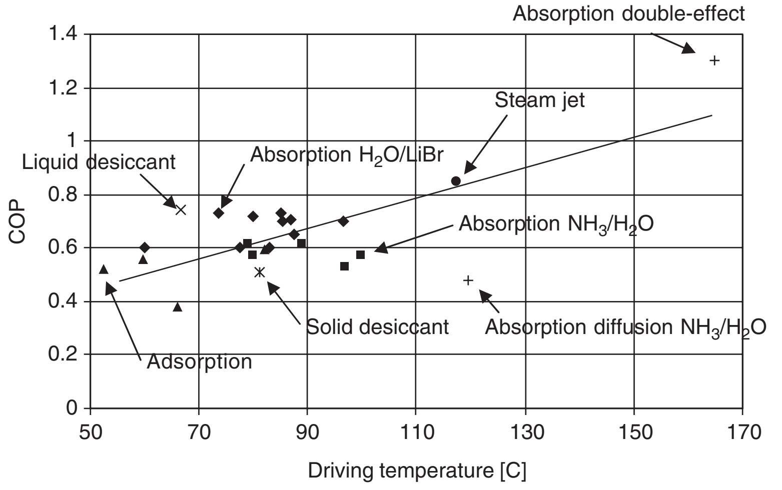


Fig. 4. COP as a function of heating medium temperature.

indirectly through the storage vessel. The auxiliary power requirement for pumps and fans is not included in this figure since it is not known for all the systems. As expected, the COP increases with the driving temperature. The low performance of the NH_3/H_2O absorption diffusion system indicates its inferiority relative to other heat-driven devices for solarbased air conditioning systems.

The average heat rejection temperature is defined as

$$T_{\text{heat_rejection}} = \frac{T_{\text{rejection_medium_out}} - T_{\text{rejection_medium_in}}}{\ln \frac{T_{\text{rejection_medium_out}}}{T_{\text{rejection_medium_in}}}} \quad (3)$$

with the temperatures expressed in Kelvin at the inlet and the outlet of the heat rejection section. The average heat rejection temperature for the reviewed projects is 30 °C. The heat rejection temperature employed for the NH_3/H_2O absorption system is generally lower than that for the $H_2O/LiBr$ absorption systems, resulting in similar COP values (Fig. 5). As expected, higher heat rejection temperatures will lead to a somewhat lower COP value.

Fig. 6 describes the initial system cost as a function of the specific collector area. The specific collector area is the installed solar collector area per unit of installed cooling capacity. The initial cost of the evaluated projects ranged from 1286 to 8420€/kW. This is the overall system cost in Euro excluding ductwork from system to application and application equipment as fan coils and induction units per installed cooling capacity in kiloWatt. The cost is related to the type of heat-driven device employed and particularly to the stage of development of its technology and working principle. However, the cost is influenced more by the cooling capacity and the solar collector type. Small cooling capacities and tracking solar collectors increase the cost significantly. The highest cost was encountered for a system at the research stage, with a small cooling capacity absorption machine (10 kW) using NH_3/H_2O and concentrating tracking solar collectors. The lowest cost was encountered for a system at the development stage, with a high cooling capacity absorption machine (700 kW) using $LiBr/H_2O$ and flat plate solar collectors.

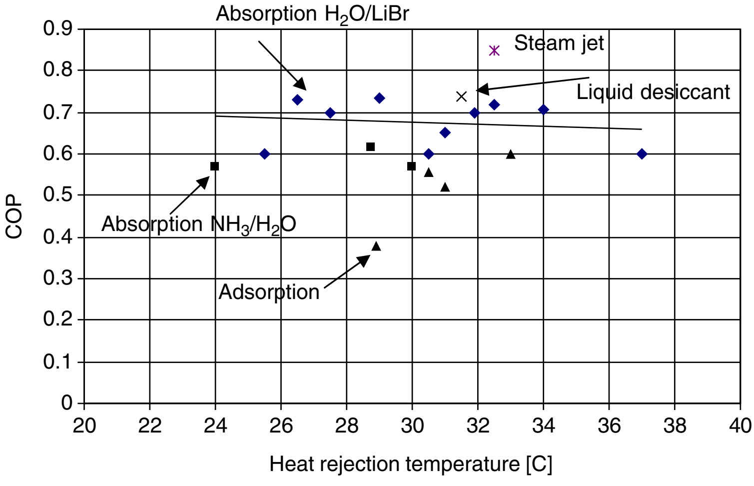


Fig. 5. COP as a function of heat rejection medium temperature.

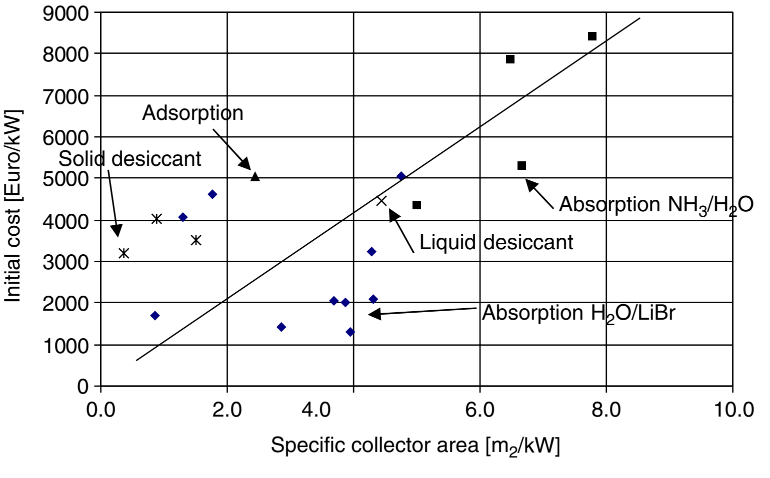


Fig. 6. Initial system cost as a function of the specific collector area.

Fig. 7 describes the annual thermal performance for the evaluated projects. The annual thermal COP is defined as the ratio of the annual cold production expressed in kilowatt hour and the annual heating input also expressed in kiloWatt hour. According to the available data on actual performance, the average annual thermal COP is 0.58, slightly lower than the design thermal COP (0.65). The H_2O/LiBr systems show the best performance, while the adsorption systems are generally less efficient. The lowest performance is shown for the NH_3/H_2O diffusion system. The grey bars indicate the systems that use flat plate collectors, the dark bars indicate the systems that use evacuated tube solar collectors, and the light bar indicates a system that uses stationary concentrating collectors.

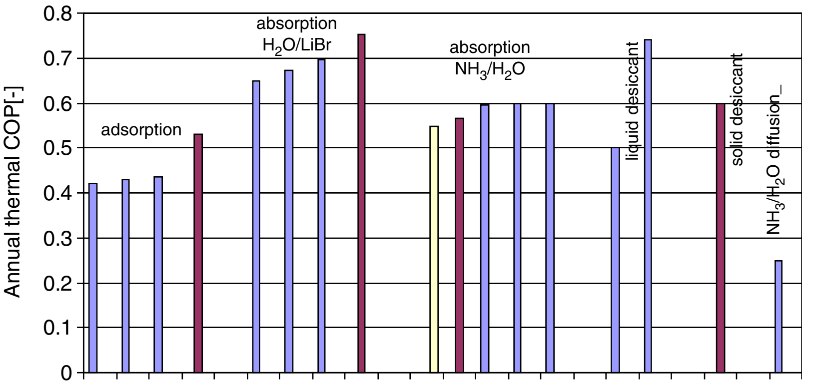


Fig. 7. Annual thermal performance for the evaluated projects.

The average electric energy consumption for auxiliary fans and pumps per kiloWatt of cooling capacity was found to be about 225 W/kWfor the evaluated systems. On average, 22.5% is lost to auxiliary power. The average specific water consumption is 5.3 kg/h per kW of average cooling capacity. The majority of the projects have water consumption between 4.0 and 6.0 kg/h per kW cooling capacity.

4.3. User guidelines

An important part of the project was the preparation of dissemination material for decision makers and building professionals. User guidelines were prepared on each of the available heat-driven cooling technologies and its application to solar assisted cooling. The guidelines identify future research and development needs and set priorities for researchers and policy makers in the field of solar energy and air conditioning. Practical information for building professionals, such as engineers, architects, building owners, planners and consultants, is also included. An important tool addressing this purpose is also the recently published handbook on solar assisted cooling [10], prepared under the IEA Solar Cooling Annex 25.

4.4. Cost-performance evaluation tool

A simplified evaluation tool ‘Easy Solar Cooling’ was developed for assessing the costperformance of different technologies and system designs. The tool assists the user to identify the most promising technologies under different operating conditions and establishes the most preferable conditions. The tool was used to evaluate different technologies and system designs of solar assisted air conditioning systems and hybrid systems with conventional installations, for different applications (loads) and meteorological conditions.

4.5. Multimedia tool

A multimedia tool containing the above results was prepared under project SACE. This tool incorporates all the project deliverables and allows the user to review the existing



Fig. 8. Overview of solar assisted air-conditioning projects—screen view from multimedia tool.

projects (Fig. 8). The user can define different screening criteria to identify specific projects based on location, type of technology, cooling technique and solar collector typology. Access is also provided to the guidelines, the economic evaluation tool and the technical reports. Along with the SACE web site, they facilitate the exchange of advanced technical information for experienced users, and background information and data for inexperienced users who want to become active in this field. An automated SACE questionnaire is provided as part of the multimedia tool, which allows a user to complete it for any new project. The questionnaire can then be submitted to SACE partners for evaluation and validation, to insure its quality. The goal is to collect information on new developments and applications, and to integrate them in the SACE database, thereby expanding it and keeping it updated.

The multimedia tool is provided both on a CD-ROM, from the authors of this paper, and is available on-line, at *http://www.ocp.tudelft.nl/ev/res/sace.htm*

4.6. Economic study

A parametric study was carried out as part of the SACE project in order to examine the current cost situation for solar-assisted air conditioning technology. In addition, the influence of improvements in the cost-performance of components such as solar collectors or thermally driven chillers or desiccant systems as well as the influence of subsidies on the economic situation was studied, and recommendations for future work were identified.

Table 1
Results of comparison of different systems for solar assisted air conditioning and heating for an office building (room area 930 m^2) in Madrid

Collector type	Collector area per $kW_{chiller}$ (m^2/kW)	Heat storage volume (m^3)	Chiller type	Backup type	Total annual costs (k€)	Primary energy saving (%)	Value of saved primary energy (€ ¢/kW h)
–	–	–	el. compr.	–	10.1	–	–
FPC	2.99	12.6	ads	heat	13.5	38	13.6
StCPC	2.99	16.8	ads	heat	14.4	52	12.7
ETC	2.13	15	ads	heat	14.9	47	15.7
FPC	2.99	12.6	ads	el. compr.	16.2	47	19.6
StCPC	2.99	12.6	ads	el. compr.	17.2	53	20.3
ETC	2.13	15	ads	el. compr.	17.7	53	22.1
FPC	2.99	12.6	abs	heat	11.7	36	6.8
StCPC	2.13	9	abs	heat	11.8	30	8.2
ETC	2.13	12.6	abs	heat	12.9	45	9.5
FPC	2.99	12.6	abs	el. compr.	14.5	46	14.7
StCPC	2.13	12	abs	el. compr.	14.6	43	15.7
ETC	2.13	18	abs	el. compr.	16	53	17.0

The method used for this study is based on hourly energy balances for a certain system which are computed using simple component models and hourly values for the boundary conditions such as meteorological data and the building cooling or heating load [10]. As an example, Table 1 presents a comparison of different system configurations to provide solar assisted air conditioning (and heating) to an office building in Madrid, Spain. The cooling capacity of the chiller for this particular building is 47 kW.Standard values have been used for all parameters, i.e. for technical components as well as energy prices. The solar collectors investigated are the flat plate collector, FPC (280 €/m^2), the stationary concentrating parabolic collector, StCPC (400 €/m^2) and the evacuated tube collector, ETC (620 €/m^2). The investigated chillers are the single effect absorption chiller, abs (400 €/kW) and the adsorption chiller, ads (800 €/kW). The investigated types of backup system are fossil fuel driven backup heater, heat (120 €/kW) and electrically driven compression chiller, el. compr. (310 €/kW). Further details can be found in the project website cited above.

The seventh column of Table 1 shows the primary energy saving compared to a conventional state-of-the-art reference system (electrically driven compression chiller with a COP of 3.0 for cooling and a conventional gas burner for heating). The parameter in the last column represents a combined cost-energy performance and is defined as:

$$C_{\mathrm{PE,saved}} = \frac{C_{\mathrm{annual,sol}} - C_{\mathrm{annual,ref}}}{E_{\mathrm{PE,saved}}} \tag{4}$$

where $C_{\mathrm{PE,saved}}$ is the cost of primary energy saving, $C_{\mathrm{annual,sol}}$ is the total annual cost for the solar system variant, $C_{\mathrm{annual,ref}}$ is the total annual cost for the reference system and $E_{\mathrm{PE,saved}}$ denotes the primary energy saving of the solar variant in comparison to the reference system.

The cost of primary energy saving listed in the last column serves as a measure for the value of energy saving and can be used during design for comparison of different energy saving measures. The results show that the best performance is achieved with common flat plate solar collectors driving a single effect absorption chiller. The best energy-cost performance (lowest value of $C_{PE,saved}$) is achieved with a collector area of about $3\,m^2/kW$ of cooling capacity of the chiller and a heat buffer storage of about $12\,m^3$ size. With such configuration, extra costs of about 6.8€ ¢/kW h of saved primary energy may be expected.

Although different locations and different cooling load profiles will lead to different results, similar conclusions are reported in [8].

5. Conclusions

Solar air conditioning has a strong potential for significant primary energy savings. In particular, for southern European and Mediterranean areas, solar assisted cooling systems can lead to primary energy savings in the range of 40–50%. Related cost of saved primary energy lies at about 0.07 €/kW h for the most promising conditions.

Further research and development activities are necessary in order to promote market integration and to reduce the cost of using solar assisted air conditioning in buildings. The SACE final deliverables will contribute in this direction since they provide practical user guidelines, tools and technical guidelines to encourage future applications of these promising technologies.

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